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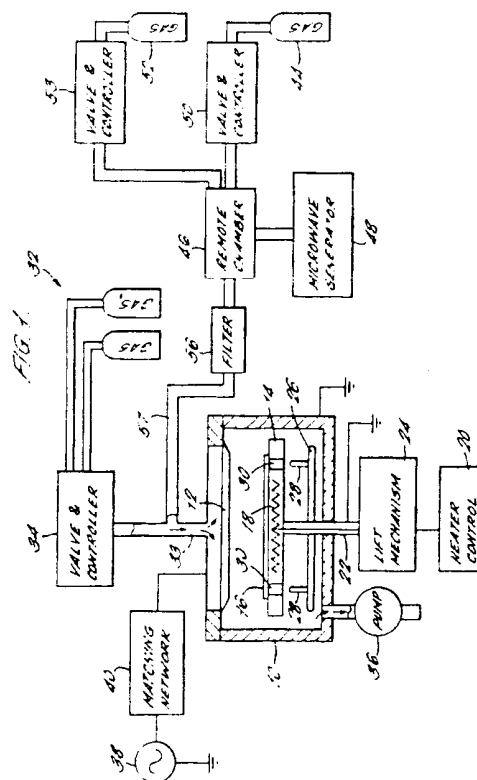
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(54) Method and apparatus for cleaning a deposition chamber

(57) A method for cleaning a deposition chamber (10) that is used in fabricating electronic devices including the steps of delivering a precursor gas into a remote chamber (46) that is outside the deposition chamber, activating the precursor gas in the remote chamber using a microwave generator (48) to form a reactive species, flowing the reactive species from the remote chamber into the deposition chamber via conduit (57), and using the reactive species that is flowed into the deposition chamber from the remote chamber to clean the inside of the deposition chamber.



## Description

Plasma assisted chemical reactions have been widely used in the semiconductor and flat panel display industries. One example is plasma-enhanced chemical vapor deposition (PECVD), which is a process that is used in the manufacture of thin film transistors (TFT) for active-matrix liquid crystal displays (AMLCDs). In accordance with PECVD, a substrate is placed in a vacuum deposition chamber that is equipped with a pair of parallel plate electrodes. One of the electrodes, e.g. the lower electrode, generally referred to as a susceptor, holds the substrate. The other electrode, i.e., the upper electrode, functions as a gas inlet manifold or shower head. During deposition, a reactant gas flow into the chamber through the upper electrode and a radio frequency (RF) voltage is applied between the electrodes to produce a plasma within the reactant gas. The plasma causes the reactant gas to decompose and deposit a layer of material onto the surface of the substrate.

Though such systems are designed to preferentially deposit the material onto the surface of the substrate, they also deposit some material onto other interior surfaces within the chamber. Consequently, after repeated use, these systems must be cleaned to remove the deposited layer of material that has built up in the chamber. To clean the chamber and the exposed components within the chamber, an in-situ dry cleaning process is commonly used. According to the in-situ technique, precursor gases are supplied to the chamber. Then, by locally applying a glow discharge plasma to the precursor gases within the chamber, reactive species are generated. The reactive species clean the chamber surfaces by forming volatile compounds with the process deposit on those surfaces.

This in-situ cleaning technique has several disadvantages. First, it is inefficient to use a plasma within the chamber to generate the reactive species. Thus, it is necessary to use relatively high powers to achieve an acceptable cleaning rate. The high power levels, however, tend to produce damage to the hardware inside of the chamber thereby significantly shortening its useful life. Since the replacement of the damaged hardware can be quite costly, this can significantly increase up the per substrate cost of product that is processed using the deposition system. In the current, highly competitive semiconductor fabrication industry where per substrate costs are critical to the cost conscious purchasers, the increased operating costs resulting from having to periodically replace parts that are damaged during the cleaning process is very undesirable.

Another problem with the conventional in-situ dry cleaning processes is that the high power levels that are required to achieve acceptable cleaning rates also tend to generate residues or byproducts that can damage other system components or which cannot be removed except by physically wiping off the internal surfaces of the chamber. For example, in a  $\text{Si}_3\text{N}_4$  deposition system

which uses  $\text{NF}_3$  for cleaning,  $\text{N}_x\text{H}_y\text{F}_z$  compounds tend to be generated. These ammonium compounds deposit in the vacuum pump where they can negatively affect the reliability of the pump. As another example, in a deposition system in which the chamber or the process kit components (e.g. heater, shower head, clamping rings, etc.) are made of aluminum, an  $\text{NF}_3$  plasma is often used to clean the interior surfaces. During the cleaning process a certain amount of  $\text{Al}_x\text{F}_y$  is formed. The amount that is formed is greatly increased by the ion bombardment that results from the high plasma energy levels. Thus, a considerable amount of  $\text{Al}_x\text{F}_y$  can be formed in the system. Unfortunately, this material cannot be etched away by any known chemical process, so it must be removed by physically wiping the surfaces.

In accordance with the present invention, a remote excitation source is used outside of the process chamber to generate a reactive species which is then supplied to the process chamber to assist in carrying out a particular process, e.g. dry cleaning the chamber. In the case of the dry cleaning process, the remote excitation source breaks down the feed gas (e.g. a compound of chlorine or fluorine) to form a long lived halogen species. A second local excitation source may then optionally be used inside the chamber to sustain the long lived species and/or to further break down the gas to form the reactive species. Since the remote excitation source is relied upon to generate the reactive species, the local excitation source may be operated at much lower power levels than are required in a conventional systems. Thus, by moving the excitation source outside of the chamber, high plasma power levels are no longer needed inside the chamber to achieve acceptable cleaning rates. Indeed, in some cases it may not even be necessary to use any local excitation source (e.g. plasma) within the chamber.

In general, in one aspect, the invention is a method for cleaning a deposition chamber that is used in fabricating electronic devices. The method includes the following steps: delivering a precursor gas into a remote chamber that is separate from the deposition chamber; activating the precursor gas in the remote chamber to form a reactive species; flowing the reactive species from the remote chamber into the deposition chamber; and using the reactive species that is flowed into the deposition chamber from the remote chamber to clean the inside of the deposition chamber.

In general, in another aspect, the invention is a method of performing a process to fabricate electronic devices within a process chamber. The method includes the steps of: delivering a precursor gas into a remote chamber that is separate from the process chamber; activating the precursor gas in the remote chamber to form a reactive species; flowing the reactive species from the remote chamber into the process chamber; using a local activation source to further excite the reactive species that has been flowed into the process chamber from the remote chamber; and using the reactive species that has

chamber. Also connected to the chamber through an outlet port is a vacuum pump 36, which is used to evacuate the chamber.

In accordance with the invention, a second gas supply system is also connected to the chamber through inlet port 33. The second gas supply system supplies gas that is used to clean the inside of the chamber after a sequence of deposition runs. By cleaning, we mean removing deposited material from the interior surfaces of the chamber.

The second gas supply system includes a source of a precursor gas 44, a remote activation chamber 46 which is located outside and at a distance from the deposition chamber, a power source 48 for activating the precursor gas within the remote activation chamber, an electronically operated valve and flow control mechanism 50, and a stainless steel conduit or pipe 57 connecting the remote chamber to the deposition chamber. The valve and flow control mechanism 50 delivers gas from the source of precursor gas 44 into the remote activation chamber 46 at a user-selected flow rate. The power source 48 activates the precursor gas to form a reactive species which is then flowed through the conduit 57 into the deposition chamber via inlet port 33. In other words, the upper electrode or shower head 12 is used to deliver the reactive gas into the deposition chamber. In the described embodiment, the remote chamber is a quartz tube and the power source is a 2.54 GHz microwave generator with its output aimed at the quartz tube.

Optionally, there may also be a source of a minor carrier gas 52 that is connected to the remote activation chamber through another valve and flow control mechanism 53. The minor carrier gas aids in the transport of the activated species to the deposition chamber. It can be any appropriate nonreactive gas that is compatible with the particular cleaning process with which it is being used. For example, the minor carrier gas may be argon, nitrogen, helium, hydrogen, or oxygen, etc. In addition to aiding in the transport of activated species to the deposition chamber, the carrier gas may also assist in the cleaning process or help initiate and/or stabilize the plasma in the deposition chamber.

In the described embodiment, there is a filter 56 in the conduit or pipe through which the activated species passes before entering the deposition chamber. The filter removes particulate matter that might have been formed during the activation of the reactive species. In the described embodiment, the filter is made of ceramic material having a pore size of about 0.01 to 0.03 microns. Of course, other materials can also be used, for example, teflon.

It should be noted that the filter can also be used to remove unwanted materials that might have been produced as byproducts of the reaction within the remote chamber. For example, if the reactive gas is  $\text{CF}_4$  or  $\text{SF}_6$  or some other halogen compound containing either carbon or sulfur, an activated carbon or sulfur species will be present as a byproduct of the activation process. It is

generally desired, however, that carbon and sulfur not be present in the deposition chamber. This is why these compounds are generally not used in conventional dry cleaning process where the activation occurs entirely within the deposition chamber. However, when the activation is performed remotely as described herein, these materials can be easily removed by using an appropriate filter material. Such filter materials are readily available in the commercial market and are well known to persons of ordinary skill in the art.

In the described embodiment, the precursor is  $\text{NF}_3$ . The flow rate of activated species is about 2 liters per minute and the chamber pressure is about 0.5 Torr. To activate the precursor gas, the microwave source delivers about 500-1500 Watts to the activation chamber. Within the deposition chamber, the RF source supplies about 100-200 Watts to the plasma. For the AKT-1600 PECVD system this implies a voltage between the upper and lower electrodes of about 15-20 volts. Of course, the precise voltage and current are pressure dependent, i.e., the current is proportional to the pressure given a fixed voltage. In any event, it is only necessary to induce a gentle plasma within the chamber, which only need be strong enough to sustain the activated species that has been flowed into the chamber from the remote source.

By using  $\text{NF}_3$  as the feed gas, we have been able to clean chambers that have been deposited with silicon (Si), doped silicon, silicon nitride ( $\text{Si}_3\text{N}_4$ ) and silicon oxide ( $\text{SiO}_2$ ). The cleaning rate for as-deposited film has reached 2 micron/minute for silicon nitride and 1 micron/minute for silicon, doped silicon, and silicon oxide. These cleaning rates are two to four times faster than the conventional cleaning process which employs only a local plasma with a power level of about 2 kilowatts at 13.56 MHz RF.

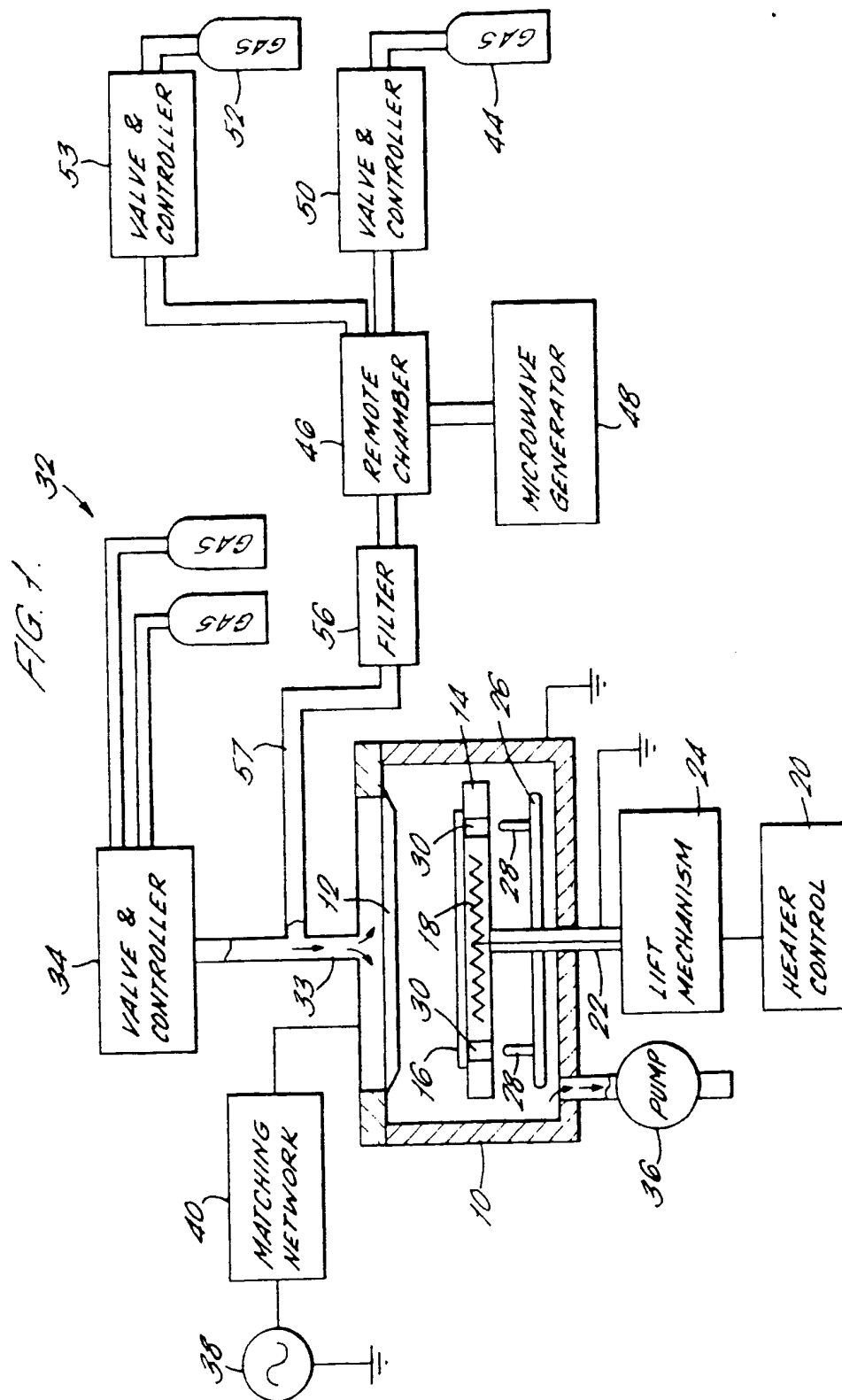
Though a microwave generator was used in the described embodiment to activate the precursor gas, any power source that is capable of activating the precursor gas can be used. For example, both the remote and local plasmas can employ DC, radio frequency (RF), and microwave (MW) based discharge techniques. In addition, if an RF power source is used, it can be either capacitively or inductively coupled to the inside of the chamber. The activation can also be performed by a thermally based, gas break-down technique; a high intensity light source; or an X-ray source, to name just a few.

In general, the reactive gases may be selected from a wide range of options, including the commonly used halogens and halogen compounds. For example, the reactive gas may be chlorine, fluorine or compounds thereof, e.g.,  $\text{NF}_3$ ,  $\text{CF}_4$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$ ,  $\text{CCl}_4$ ,  $\text{C}_2\text{Cl}_6$ . Of course, the particular gas that is used depends on the deposited material which is being removed. For example, in a tungsten deposition system a fluorine compound gas is typically used to etch and/or remove clean the deposited tungsten.

Because of the use of a local plasma in conjunction with the remote plasma, the remote activation chamber

source is an RF energy source for generating a plasma within the deposition chamber.

10. The method of claim 2 further comprising filtering the reactive species before it enters the deposition chamber to remove unwanted materials. 5
11. The method of claim 2 further comprising flowing a carrier gas into the remote activation chamber. 10
12. The method of claim 11 wherein the carrier gas is selected from the group of gases consisting of nitrogen, argon, helium, hydrogen, and oxygen.
13. A method of performing a process to fabricate electronic devices within a process chamber, said method comprising: 15
  - delivering a precursor gas into a remote chamber that is outside of the process chamber;
  - activating the precursor gas in the remote chamber and to thereby form a reactive species;
  - flowing the reactive species from the remote chamber into the process chamber;
  - using a local activation source to further excite the reactive species that has been flowed into the process chamber from the remote chamber; and 25
  - using the reactive species that has been further excited by the local activation source in performing the fabrication process in the process chamber.
14. The method of claim 13 wherein the step of activating the precursor gas is performed by using a remote energy source. 30
15. The method of claim 13 wherein the precursor gas is selected from a group of gases consisting of halogen gases and compounds thereof. 35
16. The method of claim 15 wherein the precursor gas is selected from a group of gases consisting of chlorine, fluorine, and compounds thereof. 40
17. The method of claim 14 wherein the remote energy source is a microwave energy source. 45
18. The method of claim 17 wherein the precursor gas is selected from a group of gases consisting of halogen gases and compounds thereof.
19. The method of claim 18 wherein the precursor gas is selected from a group of gases consisting of chlorine, fluorine, and compounds thereof. 50
20. The method of claim 13 wherein the local energy source is an RF energy source for generating a plasma within the process chamber. 55
21. The method of claim 13 further comprising filtering the reactive species before it enters the deposition chamber to remove unwanted materials
22. The method of claim 13 further comprising flowing a carrier gas into the remote activation chamber.
23. The method of claim 22 wherein the carrier gas is selected from a group of gases consisting of nitrogen, argon, helium, hydrogen, and oxygen.
24. A deposition apparatus that can be connected to a source of precursor gas for cleaning, said apparatus comprising:
  - a deposition chamber;
  - a first activation source adapted to deliver energy into said deposition chamber;
  - a remote chamber that is outside of said deposition chamber;
  - a second activation source separate from said first activation source and adapted to deliver energy into said remote chamber;
  - a first conduit for flowing a precursor gas from a remote gas supply into the remote chamber where it is activated by said second activation source to form a reactive species; and
  - a second conduit for flowing the reactive species from the remote chamber into the deposition chamber.
25. The apparatus of claim 24 further comprising a valve and flow control mechanism which controls the flow of precursor gas into the remote chamber.
26. The apparatus of claim 25 further comprising a valve and flow control mechanism which controls the flow of a carrier gas that is different from the precursor gas into the remote chamber.
27. The deposition apparatus of claim 25 further comprising a filter in the second conduit to remove unwanted materials out of the flow of reactive species from the remote chamber.





European Patent  
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# EUROPEAN SEARCH REPORT

Application Number  
EP 95 30 4784

| DOCUMENTS CONSIDERED TO BE RELEVANT   |   |                                  |  |
|---|---|----------------------------------|--|
| Category  | Citation of document with indication, where appropriate, of relevant passages   | Relevant to claim                | CLASSIFICATION OF THE APPLICATION (Int.CI.6) |
| X   | US-A-5 328 558 (KAWAMURA KOUHEI) 12 July 1994   | 13-20, 22-26                     | C23C16/44<br>H01J37/32                       |
| Y   | * column 3, line 18 - column 4, line 2; claim 1 *   | 21,27                            |  |
| A   | * column 5, line 58 - column 6, line 68 *   | 1-9,11, 12                       |  |
|   | ---   |                                  |  |
| X   | DE-A-41 32 559 (SIEMENS AG) 8 April 1993  | 1-9,11, 12,24-26                 |  |
| Y   | * claims 1,2 *  | 10,27                            |  |
| A   |   | 13-23                            |  |
|   | ---   |                                  |  |
| Y   | PROCEEDINGS OF THE FIRST INTERNATIONAL SYMPOSIUM ON ULTRA LARGE INTEGRATION SCIENCE AND TECHNOLOGY: ULSI SCIENCE AND TECHNOLOGY/1987, PHILADELPHIA, PA, USA, 11-15 MAY 1987, 1987, PENNINGTON, NJ, USA, ELECTROCHEM. SOC, USA, pages 805-821, OHMI T ET AL 'Ultra clean gas delivery system for ULSI fabrication and its evaluation' * page 808, line 1 - line 16 * | 10,21,27                         |  |
|   | ---   |                                  |  |
| X   | EP-A-0 555 546 (IBM) 18 August 1993 * column 4, line 37 - column 5, line 1 *  | 1,2,6-8                          |  |
|   | ---   |                                  |  |
| X   | PATENT ABSTRACTS OF JAPAN vol. 005 no. 015 (E-043), 29 January 1981 & JP-A-55 145338 (TOSHIBA CORP) 12 November 1980, * abstract *  | 1,2,6-8                          |  |
|   | ---   |                                  |  |
| X   | US-A-4 867 841 (LOEWENSTEIN LEE M ET AL) 19 September 1989 * claim 1 *  | 13-20, 22,23                     |  |
|   | -----   |                                  |  |
| The present search report has been drawn up for all claims  |   |                                  |  |
| Place of search   |   | Date of completion of the search | Examiner                                     |
| THE HAGUE   |   | 20 October 1995                  | Ekhult, H                                    |
| <p>CATEGORY OF CITED DOCUMENTS</p> <p>X: particularly relevant if taken alone<br/>Y: particularly relevant if combined with another document of the same category<br/>A: technological background<br/>O: non-written disclosure<br/>P: intermediate document</p> <p>T: theory or principle underlying the invention<br/>E: earlier patent document, but published on, or after the filing date<br/>D: document cited in the application<br/>I: document cited for other reasons<br/>A: member of the same patent family, corresponding document</p> |   |                                  |  |

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